Chapter II

Capabilities and Technologies

1.0 Introduction

We define a set of capabilities which, we believe, are synonymous with an effective Air Force, and we believe that others will agree to their importance. They do not match accepted Mission Areas for two reasons. We experimented with Mission Areas at the Spring Workshop[1] of *New World Vistas*. We found that Mission Areas were closely related to existing capabilities, and we naturally began to think of new technologies as producing evolutionary enhancements to existing capabilities. Many participants thought that the categories were too narrow and restrictive. Second, when we collected the new ideas they formed categories which mapped into the Mission Areas, but the ideas each applied to several areas, and we began to generate a complex set of charts. Constructing the map is straightforward and instructive, but we leave it as an exercise for the interested reader. We decided to form a set of categories which were natural ones for the technologists and, simultaneously, meaningful for the operators. These primary capabilities, as viewed by the technologist, are entirely consistent with the capabilities of Global Reach-Global Power and the Air Force Core Capabilities. These categories form a bridge for discussion between scientist and warfighter, and we felt that to be a dominant factor in an activity such as *New World Vistas*.

We reduced the list of essential capabilities to a basic few. We intentionally made the categories broad to encourage broad thinking about important problems. The list is short and is meant to be viewed in the context of the Air Force concept of Global Reach-Global Power. The primary capabilities are:

- Global Awareness
- Dynamic Planning and Execution Control
- Global Mobility in War and Peace
- Projection of Lethal and Sublethal Power
- Space Operations
- People

One can argue that the categories mix support, or infrastructure, and operational capabilities, and that is, indeed, true. However, the 21st century will be characterized by an increasing reliance on devices which operate at the edge of technology and by an increasing worldwide infrastructure in space. Therefore, the education and training of Air Force people will enable all operational capabilities. We must remember, too, that space will contain major threats to the security of the Nation and its Forces as well as containing important operational assets. We believe that Space Operations and People deserve equal footing with the other capabilities.

Each of the capabilities expand to include many subcategories, and each depends on many technologies. In this chapter, we will describe the capabilities and relate the technologies to them. The major technologies will be listed in Chapter III. Do not expect completely logical one-to-one correlations or extremely detailed expositions in this volume. Those features are

1. *New World Vistas* Spring Workshop, Maxwell AFB, AL, 2-5 May 1995

characteristic of the Panel volumes. We will direct the reader to the appropriate volume through footnotes.

It is our intent to emphasize the close integration of the technologies and the capabilities with one other. Therefore, we will refer to some systems or technologies several times in the chapter. This is not an unintentional redundancy. It is to impress on the reader that capability is based on dependency. We can not afford -- financially or operationally -- to have all systems self contained to the extent that they are now. Offboard sensors and weapon control provide enhancement of capability far beyond their cost. Replicating information functions on all weapon platforms is not only extravagant, it is also less operationally effective than central information processing.

The list of essential capabilities reflects the effect of uniting the Air Force with technologies that will produce a discontinuous enhancement of Air Force capabilities. Those technologies are variously named "high leverage", "revolutionary", or "explosive growth" technologies. A more useful and accurate description is that certain technologies are "coming of age". Information technologies are now an essential part of all Air Force activities, and they will be even more important a decade from now. We should remember, though, that computer programming was an undergraduate course at many universities in the 1950's. The transistor, which makes it all possible, was invented in the 1948. We illustrate this concept intuitively in Figure II-1, which is a graph of a parameter, which we call "importance", that started with a value of 1 and doubled every four years. Importance could be computer speed, PGM performance, or another important measure of the value of a technology.

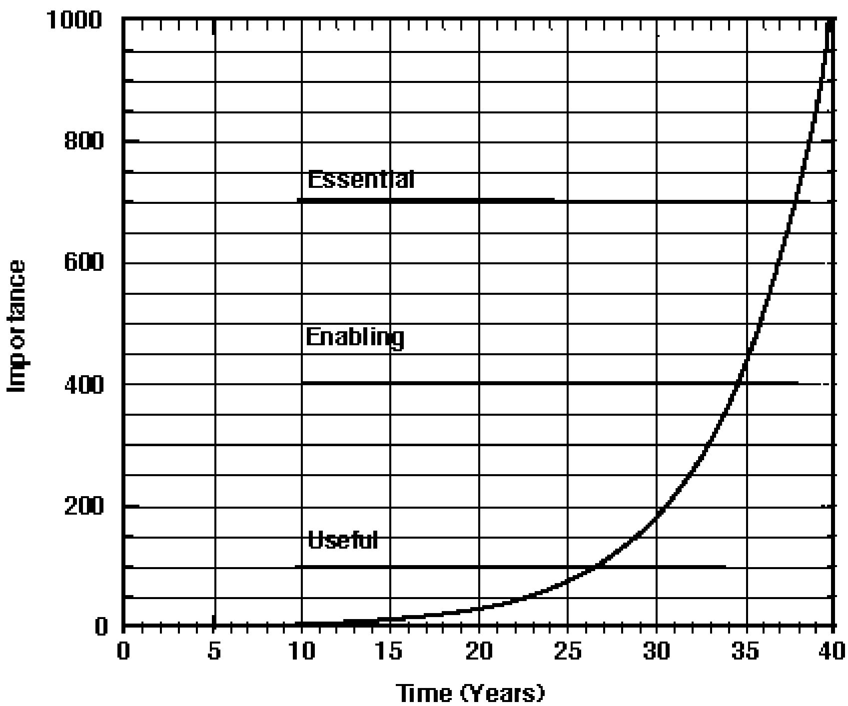

Figure II-1

If one looks back from a period when the importance has grown by a factor of 1000 from its initial value, the growth seems to be explosive for the past most recent decade, but it seems that nothing much happened for the first 20 years. In fact, the relative growth was constant. This is not a new observation, but it makes the graphical point that in *New World Vistas*, we are trying to define capabilities that make immediate and efficient use of technologies which have passed the “700” point. Next, we will show uses and effects of the technologies which have passed the “400” point. Finally, we will suggest new capabilities which will demonstrate the use of technologies at the “100” point. One could, for example, identify these states with information technologies, space technologies, and directed energy technologies, respectively.

2.0 Global Awareness

Global awareness means that the Air Force can use affordable means to derive appropriate information about one or more places of interest after a delay which is short enough to satisfy operational needs. This is the goal of the capability we call Global Awareness, but the definition is far too vague to be of practical use. We will explore the idea by describing the strengths and weaknesses of the systems which can make it possible. There is a strong commercial component here, and we will show the connection between military and commercial applications. The systems which enable Global Awareness form a truly joint capability. Although we describe Global Awareness in an air and space context, the application to sea and land should be clear.

Technology has for years made it possible to build relatively inexpensive observation platforms in space which will deliver images from optical or radar sensors at resolutions better than one meter. Images from a few systems are commercially available now, and there will soon be competition among companies to deliver the best product. The Air Force, or the Defense Mapping Agency, should purchase these products for mapping the world at a resolution of one meter. This provides Global Awareness of a sort, but the latency time for a world map is expected to be 90-180 days with local updates of, say, 100 mile square areas in 24-48 hours. A dedicated system could provide high resolution images of several small areas daily. This is an essential capability, but it is not completely adequate.

Mapping at present consists of a huge number of products both digital and analog constructed on an array of coordinate systems with varying precision and accuracy. First a common grid based on WGS-84 should be defined. It may be useful to supply maps which are expressed in unique coordinates, but the source for all these maps should be a common database. The database can be supplied by the commercial imaging system described above. It is not likely, however, that absolute accuracy will be one meter, but it is possible to devise a GPS-based method of calibrating the images. Collaboration with the commercial supplier in satellite design could make the calibration task easier. The goal of precision mapping should be to equip each aircraft and planning system with a map of the entire world to one meter accuracy. The map will require 10-20 terabytes with suitable compression. After the creation of the initial map, only updates need be supplied routinely. Onboard storage will minimize data transmission needs. Storage density will be adequate in a decade. We refer to the high resolution onboard digital map as the “onboard world.”

The “onboard world” will enable the ultimate in moving map navigation and self contained, undetectable terrain avoidance. The information can be coupled with navigation aid and airport information supplied by commercial vendors. All Air Force aircraft will have the navigation database to fly anywhere, anytime, on any route independent of external data.

2.1 Distributed Satellites

The manifestation of the concept of Global Awareness is one of distributed constellations of small satellites[2] which cooperate with airborne and ground sensors. We must divest ourselves of the mindset that spatial resolution is the only criterion for evaluating surveillance systems. There are indications that one can derive target information from spectral data coupled with low resolution position information. A system of satellites each having a spatial resolution of 10 meters and, say, 100 spectral bands in the visible and infrared could provide worldwide coverage instantly on demand. Communication limitations will restrict the number of areas which can be covered simultaneously, but even this restriction will disappear as laser cross- and downlinks become commonplace. Laser links will approach the capacity of fiber, where 40 Gb/s is becoming routine. Onboard processing and compression can increase information transfer rates. Because of higher cost and the $1/R^4$ dependence of signal on satellite altitude, Synthetic Aperture Radar (SAR) systems will be fewer than optical systems, and SAR images will have a latency time of an hour or two.[3] Active systems could also include Light Detection and Ranging (LIDAR) for chemical and biological agent detection in clear weather and for precision weather observations. These systems will provide missile warning and will enable the tracking of mobile rocket launchers and SAM systems. They can also provide weather information at a level of detail appropriate for combat and mobility operations. High resolution active and passive systems can augment the lower resolution data at revisit rates of one per day. The cooperative, distributed satellites will establish long baselines for precise location of radio frequency emitters on the surface and in space. It will be possible to locate an emitter to an accuracy that will permit the launch of a precision guided munition using GPS coordinates even if transmissions cease.

Onboard processors will make it possible to identify and track moving targets to the extent that tracking and identification can be done by infrared hyperspectral systems. Complete Airborne Warning and Control System (AWACS)-like performance will be enabled at the second stage of deployment[4] with a combined air and space based system. High resolution radar from space can be enabled by the capability to deploy large, lightweight space structures. Given power available in space, continuous operation of high resolution radar will necessitate antennas having diameters of kilometers. Development of appropriate structures and materials coupled with technologies for correcting RF wavefronts to compensate for antenna imperfections will make space based radar possible. If one requires only limited coverage, say 500 km (the limited diameter), the peak power of a space based radar system can be increased by operating at a duty cycle of only 1/250. It is then necessary, however, to launch enough satellites to provide continuous coverage. Such a system is not likely to be affordable. A bistatic space-based arrangement with transmitter and receiver separated may provide some relief. The receiver can be composed of a distributed constellation to construct an instantaneous synthetic aperture.

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2. Space Applications Volume
3. The fundamental equation of RADAR shows that the detected signal is inversely proportional to the fourth power of the distance, R, to the target. It is this strong dependence on distance that severely limits the range of a RADAR system.
4. Sec. 2.2 of this chapter

A detailed design of a bistatic system may point the way to cost savings, but the prospects are not encouraging for the next decade. The Uninhabited Reconnaissance Aerial Vehicle (URAV) appears to be the most cost effective vehicle.

Observe that 10 meter resolution does not restrict location to 10 meters. Centroid location is a question of signal-to-noise, and there is no reason that centroid location cannot be done to 2-3 meters. Thus, lower spatial image resolution can be coupled with precision targeting. If the target can be identified with a low resolution hyperspectral imaging system, the aimpoint can be located to approximately 2 meters. It appears that, if preliminary experiments are verified, the 10 meter hyperspectral system will provide a global observation system which is affordable and effective. We have defined the following space based system to provide maximum affordable coverage world-wide:

1. Continuous multi-spectral observation at 10 meter resolution with 2-3 meter targeting
2. Continuous location and targeting of RF emitters to 10 meters
3. SAR with 1 meter resolution once per hour
4. Sub-meter resolution once per day, multispectral and SAR

2.2 Standoff Systems

The systems described in Sec. 2.1 are non-intrusive. At the next level of involvement other possibilities arise. If it is possible to position vehicles within 200-300 nm of a region of interest,

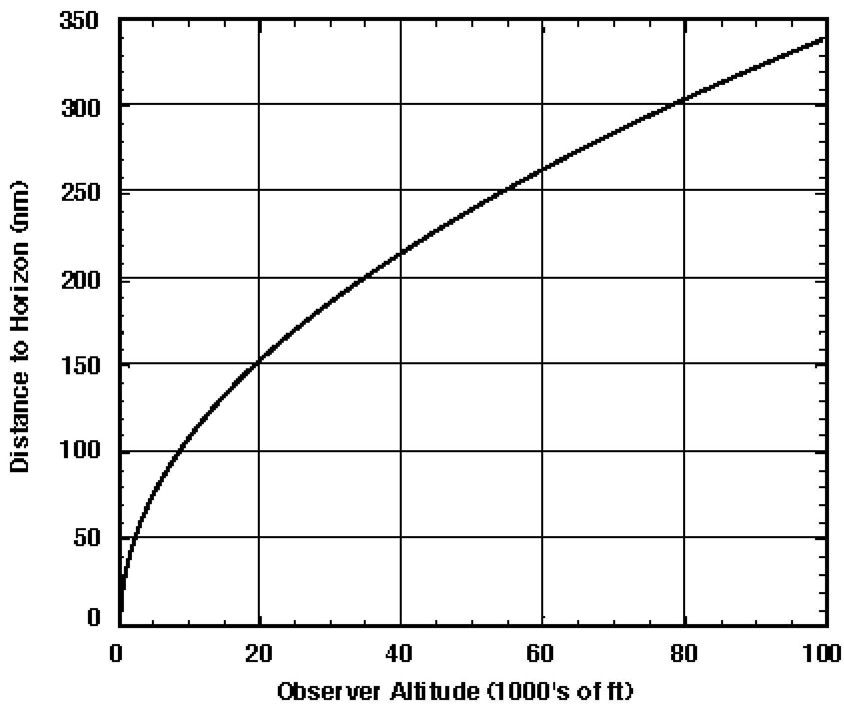

Figure II-2

high resolution staring sensors and SAR's can be carried on URAVs that loiter at 50,000-100,000 feet. Figure II-2 shows range to the horizon from a given altitude.

Continuous monitoring at a resolution of one meter or less is possible. URAVs can work cooperatively with satellite constellations by projecting high power RF beams over the area of interest. The satellites receive reflected signals from targets near the earth to form a distributed bistatic synthetic aperture radar system. Clutter rejection is improved because of the varying reflection angles to different satellites. Moving and fixed targets can be detected with high resolution as the result of the long baseline between satellites. This arrangement limits the number of expensive spaceborne transmitters by restricting coverage to a region of interest. We have added:

5. Continuous Multispectral and SAR observation at 1 meter resolution
6. Continuous bistatic detection and tracking of fixed and moving targets over a limited area

2.3 Overhead URAV Systems

Further improvement in resolution can be obtained in situations where overflight of enemy territory is authorized. Low observable URAVs can carry staring and scanning sensors which produce multispectral and SAR images and LIDAR returns at few centimeter resolution. The URAVs can deploy low altitude or ground based chemical sensors for accurate discrimination of Chemical & Biological (CB) agents and the effluents from Chemical, Biological, and Nuclear (CBN) manufacturing plants. These sensors can be interrogated by driving readout with an RF or optical signal from a satellite or a URAV. The remotely read sensor will have reduced size, weight, power, and vulnerability. Now, the system consists of:

7. Continuous multispectral and SAR observation at 1 centimeter resolution
8. Contact sensors for CBN detection.

2.4 Unattended Ground Sensors

We mentioned the integration of ground sensors into the Global Awareness network as CBN detectors, but a few specific observations should be made. Unattended ground sensors are at present difficult to deploy and to monitor. Deployment by manned intrusion, air or ground, is the norm.[5] It is not clear that deployment and operation are Air Force missions. Technologies now under development and the need for detailed awareness in specific areas of the world can change the situation completely. In addition to CBN detectors, ground sensors are natural candidates to monitor the local weather. *Weather monitoring from space is possible, but ground monitoring can be more accurate, more continuous, and far less expensive.*

Ground sensors can be deployed by miniature UAV's carried aboard larger UAV's. Microsensor development is proceeding, and, as noted, novel readout methods which have a low probability of intercept (LPI) have been proposed. *The Air Force should investigate the advantages of ground sensors for local monitoring before committing to more expensive space and airborne sensors.*

5. Sensors Volume

2.5 Practical Considerations

It is in the region where friendly and enemy airspace meet that the AWACS and Joint Surveillance, Target Attack Radar System (Joint STARS) systems will begin to participate. These systems will continue to be very valuable for the next decade, but it is now time to consider the next generation. Some of the functions of these systems can be implemented in space, but for continuous coverage aircraft, deployment appears to be more practical. The $1/R^4$ factor in the radar equation exacts great concessions from a space based system. The geometric factor and the limited power from the satellite power bus will limit coverage area severely. The deployment of airborne transmitters and satellite receivers in a bistatic geometry as described above is possible, and this may be the ultimate system. After a decade from now, URAV deployment is likely to be the method of choice, although there is a long term possibility for shifting the balance of continuous surveillance completely back to space. It has been proposed that very large, lightweight structures can be deployed in space to create optics and antennas having dimensions of kilometers.[6] It is the product of power and aperture that determines signal-to-noise, all other factors being equal. The URAV and space options are attractive as replacements for AWACS and Joint STARS. Both the AWACS and the Joint STARS use much of their volume for crew and displays, and loiter time is restricted by fuel consumption and crew limits. The systems of the early 21st century should use high speed processors which will exceed current performance by a factor of 10,000 for AWACS and 1000 for Joint STARS. Processor volume should be no more than 1 m^3. Communication rates of 100 MHz to satellites will be practical almost immediately, and lasercom will appear in a decade. Multiple URAVs can detect and process signals coherently to provide large increases in resolution, and loiter times of tens of hours without refueling are possible.

It is unlikely, of course, that the entire collection of sensors would be deployed simultaneously in a single area of interest. The arrival of higher resolution systems can free the lower resolution systems for use at the periphery of the area of interest.

These systems offer the possibility of monitoring the entire world continuously at reasonably high resolution. By now, the reader has realized that the data rate may be impossibly high. Consider that the actual information content from a 10 m system is one bit per pixel spatial and 100 bits spectral. Both SAR and visible images assume that the total information content is 100 bits/pixel over the entire world once per hour. The data rate is approximately 40 GBits/s continuously. If we observe one percent of the world, $1.3X10^6$ km^2, at a rate of once per second the data rate is $1.3X10^{12}$ /s (1.3 TB/s). State of the art for a single optical fiber is 40 GB/s, and 1.3 TB/s necessitates only 40 fibers. In 10-20 years laser cross- and down-links will be capable of these rates, too. The important issues, however, are: Why would one want so much information? Who would look at it? How much would be stored? How would it be analyzed? The possible is not necessarily the sensible.

Surveillance of all of Iraq at a rate of once per hour would produce a data stream of only 85 MB/s, and once per minute would require 5 GB/s. More reasonable problems produce more reasonable communication rates. Certainly, these rates are not out of the question today, and they will be delivered routinely in a decade.

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6. Space Applications Volume

Satellite numbers are given in the Panel volumes.[7] We mention number here because it is connected to significant issues of cost and commercial involvement. There are many factors involved in determining the satellite number, but the range will be 100-300 satellites. These numbers are similar to those of the Iridium or Teledesic systems, because the coverage considerations are also similar. The 10 m resolution chosen for the distributed system is also consistent with the size of the commercial satellites. In fact, it may be possible to install passive multispectral sensors on the commercial satellites and to share satellites and communication systems. Ownership of satellite systems by multinational corporations may make sharing undesirable from both the US Government and from the corporation points of view. It may be possible, however, to buy standard satellites from the commercial organizations and to modify them for military purposes. *We estimate the cost of modification for an independent military system to be $10-20M per satellite. Active sensors are more expensive but they will be fewer. For launch costs of $10,000/kg, the weight should be kept below 100 kg to make deployment cost effective.*

2.6 Dissemination of Information

So far we have discussed the part of Global Awareness related to learning about an adversary or about a situation. We have also described it mostly in terms of sensors. There is much more to it than that. We must have a perfect picture of our own and allied forces as well. The picture should include aircraft maintenance status, crew health and availability in addition to location and mission status. The mass of data associated with our own forces is large, but it can be organized by common agreement. It is probable that each Service will configure its databases and information systems in a unique way, and it is certain that our allies will do so. *There is no reason for the differences to limit system effectiveness, but a generic capability to operate across dissimilar networks will be essential.*

Another class of information is essential to Global Awareness. That is information derived from the databases of the adversary. Techniques for mapping and penetrating the military and commercial systems of the enemy are needed. The penetration of enemy databases will, frequently, be more valuable than destroying a Command, Control, Communications, Computers, and Intelligence (C4I) system for obvious reasons. The inverse of penetrating enemy systems is protecting our own. As we become more dependent on integrated information systems we must protect them vigorously. *The Air Force must develop protection technologies*.[8]

We have discussed the collection of data. It has been shown that the communication of data to analysis stations is within the state of the art. The information will be processed and correlated at a few centers . This is not a trivial problem, but we know how to solve it. *Analysis and correlation of data must be done across databases having thousands of variables.*

The final action is the transmission of appropriate information to the nodes which need it.[9] Transmission and request must be done in both directions from operational nodes to information centers and from node to node. There is a growing tendency to demand wide area broadcast of information. Broadcast will be of use while ground based fiber networks are not available and where only a few geosynchronous satellite channels can be used. Broadcast will be useful

7. Space Technology Volume
8. Information Applications Volume
9. Ibid

in the near future when the total volume of sensor data is small, but the amount of information increases, broadcasts will become cluttered or will contain many frames. The full internetting of nodes will enable each node to construct data flow and presentations which satisfy the unique needs of that node. Broadcast of information tends to generate specialized transmission and receiver systems which can be of limited utility. The need for broadcast rather than unique presentation to each node should be verified carefully. It is certainly true that Direct Broadcast Television (DBTV) has become a commercial product with 100 channel capability in a ground station which sells for less than $1000. Most of the cost, of course, is in the space segment and in the generation of programming. *Information broadcast in the DBTV mode will be an important interim capability, but eventually it should be integrated into an "information on demand" system.*

2.7 A Necessary Adjunct System

Almost all of the processes related to Global Awareness need precise and absolute positioning and timing. The most reliable and the least expensive way to provide it is through a space based Global Positioning System (GPS). As the precision of all operations increases, so must that of GPS. *We strongly suggest that the Air Force develop a system that has 30 cm spatial accuracy and 1 ns timing accuracy.*[10] All services are now dependent on GPS, and as that dependence grows, and it will, protection of GPS capability is essential. The receiver enhancement methods now proposed will not be completely adequate as the capabilities of our enemies grow. The satellites and codes must be redesigned to provide both adequate performance and adequate protection.[11] *Code chip rate can be increased by a factor of ten, and signal power can be increased by a factor of 100 to give an improvement in jamming protection of 30 dB.*

2.8 Databases

The concept of Global Awareness is a complex one. Much of the information which is needed to construct the global picture exists today in computers somewhere. *The problems of the next decade are to identify the relevant databases, to devise methods for collecting, analyzing, and correlating them, and to construct the needed communication and distribution architectures.*

2.9 Strategy

The summary of Global Awareness is an extended one. We justify the length by noting that it is here that the commercial interface is likely to be most extensive. *Close attention must be paid to the use and optimization of commercial information, satellite, and space launch capabilities*. This task is not a familiar one to the Air Force. It involves major changes in the ways needs are interpreted and in the ways that systems are designed, procured, and discarded.

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10. Space Technology Volume
11. Munitions Volume